September 2007

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This is not a peer-reviewed article.
International Symposium on Air Quality and Waste Management for Agriculture. CD-Rom Proceedings of the 16-19 September 2007 Conference (Broomfield, Colorado)
Publication date 16, September 2007
ASABE Publication Number 701P0907cd

Association of Odor Measures with Annoyance: An Odor-Monitoring Field Study

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Abstract. *Multiple assessments of ambient odor were made by trained individuals in the vicinity of a swine finishing operation in eastern Nebraska during the summers of 2005 and 2006. This paper addresses an analysis of assessor responses in Year 1 of this field study to determine what relationships existed between field odor measurements/ratings and ratings of annoyance potential, and to identify candidate measurement threshold values for odors that are likely to cause an annoyance. The first-year results showed that the likelihood of odor causing annoyance increased as ambient odors became more offensive, more intense, and more concentrated, with* r^2 *values of 0.89, 0.81, and 0.64, respectively. Selection of threshold values for predicting annoyance depends on the extent of annoyance to be considered. In this analysis, candidate thresholds were sought to delineate both 'any degree of stated annoyance' and 'consequential annoyance' – defined as a state of odor that would likely invoke a change in behavior or activity level by the receptor and instill some memory of the odor event afterwards. Based upon the first-year results of this study, candidate thresholds for any stated annoyance and consequential annoyance, respectively, appear to be: 1 and 2 for intensity (on a 0-5 scale); 2 D/T and 7 D/T for odor concentration (as measured using a mask scentometer; and -1 and -2 for Hedonic tone (on a +4 to -4 scale). Further study is needed to verify these threshold values with other operations and animal species, as well as to clarify the relationship between odor intensity and concentration when measured in the field.*

Keywords*. Odor intensity, Odor concentration, Hedonic tone, Rural communities, Swine facilities, Field olfactometry.*

Introduction

As livestock production has become more concentrated and the make-up of rural communities has changed, neighbor complaints about odors from livestock operations have increased in number and visibility to the point where odor concerns are a primary barrier at the local level to growth of livestock operations. Dispersion modeling may facilitate producers being able to evaluate the expected extent of odor impact from their operation on neighbors, and control strategies are being developed to mitigate odor emissions. Credible field odor measurement techniques are needed, though, to help demonstrate the benefits that improved site selection and odor control may offer to rural residents.

While progress is being made in measuring ambient odors using electronic devices such as an e-nose (Omotoso et al., 2005), using humans to make field measurements of ambient odor remains the most widely accepted approach. People with a normal range/sense of smell can be trained to provide fairly consistent, calibrated responses for odor intensity and odor concentration. People can also provide subjective ratings of odor offensiveness (via Hedonic tone), odor character, and the potential for annoyance.

More cause-and-effect information on measurable odor parameters and the potential for odor to be annoying is needed. Odor having an intensity of 2 or greater (on a 0-5 scale) has been assigned as a threshold for annoyance (Guo et al., 2005), but has not been verified with supporting data. Odor concentration is often used in odor regulation, with 7 dilutions to threshold (D/T) or odor units (OU) being a common regulatory threshold for states that consider ambient odor levels within their regulations (Iowa DNR, 2006). Odor offensiveness (negative scale of hedonic tone) and annoyance are often used interchangeably, even though the definitions of each differ.

Odor concentration is usually used as the determinant of an annoying state of odor in dispersion modeling packages. For example, the Odor Footprint Tool is based on AERMOD (an EPA model) concentration output, and 75 D/T is commonly input as the threshold for annoyance. The selection of 75 D/T was based upon published correlations of odor concentration with intensity (Nicolai, 2000), using measurements made in an olfactometry laboratory, with 75 D/T being shown to correspond to an intensity of 2 for swine systems. Nicell (2003) suggested using dose-response trends in assessing the potential for odor annoyance and resulting statistical expressions when modeling odor impact in rural communities.

To help validate use of the Odor Footprint Tool (Stowell et al., 2005) as an odor impact / setback-estimation tool, the University of Nebraska-Lincoln conducted a field study of ambient odor levels in the vicinity of a livestock facility during 2005-06. The design of the field study was adapted from a study conducted by Guo et al. (2001) to calibrate the Inpuff-2 dispersion model for odor and to help validate use of the OFFSET setback-estimation tool (Guo et al., 2005). The field data was analyzed to determine individual relationships of odor intensity, concentration, and hedonic tone with perceived annoyance potential. This paper reports the analysis results and comments on candidate thresholds for predicting annoyance potential.

Methodology

Study Participants:

Three separate groups of people were trained in field olfactometry methods and employed to make 'objective' assessments of odor in the vicinity of a swine finishing operation in eastern Nebraska. During July and August of 2005, graduate students from the University of Nebraska made weekly visits to measure and rate ambient odors downwind of the primary (4800-head) facility and at three set locations around the facility. These 'mobile odor assessors' traveled as a group under the guidance of a scout and a team leader who located the odor plume and oversaw the collection of data, respectively. Assessments were made by five to seven people every Tuesday for 6 weeks, with one assessment period occurring during the early evening (before dusk) and another taking place later in the evening (after sunset). From mid-May to mid-August of the following year, assessments were made by two other groups. One group consisted of two residents of a town about 10 miles (20 km) away from the area. With occasional assistance and oversight from the previous year's scout, these individuals traveled together into the area two to five times a week to make assessments downwind of the primary facility (similar to what was done the previous summer). The third group consisted of seven area residents, referred to as 'resident odor monitors', who owned houses within 2 miles of the primary facility. This paper summarizes the analyses of data collected by the mobile odor assessors during 2005 only.

Study participants attended a daylong training seminar where they were instructed in the use of a mask scentometer and assessing odor intensity. The training included field exercises where participants calibrated their noses to equate ambient odor levels around a swine facility to standardized reference intensities. Individual abilities to sense odor were evaluated during the training exercises and periodic sensitivity testing using n-butanol reference concentrations (St. Croix Sensory, 2006). All mobile odor assessors in this study demonstrated a normal range of osmotic sensitivity (i.e. no hyper/hypo-sensitive individuals).

Measured Parameters and Scales:

Odor intensity: Field odor intensity was measured on a 0-to-5 scale. The method was adapted by the University of Minnesota (Guo, et al., 2005) from ASTM Standard E 544-99, "Standard Practices for Referencing Suprathreshold Odor Intensity", which references field intensity measurements to a standardized n-butanol scale of 12 concentrations ranging from 10 to 10,000 ppm. The resulting method reduced the scale to 5 levels so that odor assessors could readily commit reference intensities to memory.

Odor concentration: Odor concentration was measured using a special mask fitted to conduct field olfactometry. Readings were taken by turning a dial on the mask through a series of notches that corresponded to increasing dilution ratios of ambient (odorous) air to air that was cleaned by being passed through a carbon filter (Henry, 2006). When the dilution setting first reached the point at which the person wearing the mask could recognize the odor, the detection threshold (DT) setting was recorded. The mask DT settings corresponded to dilution ratios as follows:

A = 170 D/T (dilutions-to-threshold)	D = 7 D/T
B = 31 D/T	E = 2 D/T
C = 15 D/T	Non-detect ➔ 1 D/T

For reference, a mask DT of 170 dilutions-to-threshold is conceptually the same as an odor concentration of 170 odor units (OU).

Figure 1. Mask scentometer for performing field olfactometry.

Hedonic tone: Hedonic tone ratings were made to assess the degree of unpleasantness or pleasantness of odor using a -4 to +4 scale.

Odor character: Study participants entered descriptive terms to characterize assessed odors, using a list of prospective terms as a guide. Selected terms were adapted from an *odor wheel* used in general odor evaluations (McGinley, 2004).

Annoyance potential: Participants also were asked to rate the degree of annoyance that they would likely experience if the present state of odor existed outside their respective residences. The rating scale was designed to incorporate two response parameters that appeared to be generally associated with nuisance events: the prospective nuisance i) affects behavior and ii) invokes remembrance of the event. Odor assessors were asked to communicate their likely response using the following scale and symbols:

Rating:	Symbol	Likely behavioral response, memory effect:
Not annoying	O (0)	No response or effect
Slightly annoying	S (1)	Make no changes in activities or routine; short-term recall
Moderately annoying	M (2)	Alter routine/activities to reduce exposure; recollection fades
Highly annoying	H (3)	Postpone activities or stop sooner than planned; lasting effect
Extremely annoying	X (4)	Stop activities to find relief / leave area; engrained into memory

Study participants were instructed to associate the strength/degree of their expected responses with the assigned rating. To help establish a common basis for making these ratings, participants were to picture themselves having invited friends/family over for an informal outdoor gathering. Beyond establishing the rating scale and common basis for making ratings, no attempt was made to calibrate participant responses. In analyzing this data after it was collected, it was convenient to use a 0-to-4 scale to represent annoyance potential, as indicated by the assigned number in parenthesis after each symbol.

Each individual assessment was, therefore, comprised of two relatively objective measurements (odor intensity and mask DT) and three subjective measures (Hedonic tone rating, the odor characterization, and the rating of annoyance potential).

Measurement Data Collection:

Study participants were provided with field olfactometry masks, clipboards with data sheets, and head lamps. Certain common information was recorded for each odor monitoring event, including the date and time, and basic weather conditions.

When assessing detectable odor, the assessors made twelve sets of mask DT and field odor intensity readings. Participants began each set with all inhaled air coming through the carbon filter. They then cycled through the mask dilution settings, from highest dilution to lowest, until the source odor was first recognized. After recording the mask DT setting, each assessor briefly pulled the mask away from his/her face to assess the intensity of the ambient odor on a 0-to-5 basis and then recorded it with ½ increments permitted. Participants then made another 11 sets of DT and intensity readings, with each set typically taking 30 to 40 seconds to complete. When all 12 sets of DT & intensity readings were made, each assessor assigned a Hedonic tone rating, an odor descriptor, and an annoyance potential rating to represent the general state of odor during the measurement period (typically 8-10 minutes). All data sheets were coded using mask ID numbers to maintain confidentiality. A graduate student working on the project retrieved completed data sheets regularly, either in person or via mail delivery.

Odor assessors were required to refrain from drinking caffeinated drinks, eating spicy foods, and wearing perfume or cologne on the days in which they participated in the study. Before leaving for the study area, they practiced assessing odor intensity using reference vials of n-butanol and, as a group, calibrated themselves to the reference odor strengths. Before arriving at the site, mobile odor assessors ensured that their mask scentometers were clean and fit properly.

Once the group entered the study area, assessors put their masks on so all inhaled air was filtered. An individual acting as scout located the odor plume at a location ½ mile to 1 mile (800-1600 m) downwind of the facility (via roadways and available access lanes), and helped position the group to be properly exposed to the odorous air stream. Then, the assessors took readings as described above at the given location.

From this first assessment location, the scout sought to locate the odor plume at more distant locations, which was not always possible, and guided the assessors in taking an additional round(s) of readings. In this study, odor from the primary facility was detected by one or more individuals as far as 2 miles (3,200 m) away on a couple of occasions, while on other occasions, the scout found it fairly challenging to find the odor plume beyond the perimeter of the site (an expected scenario based on varying weather conditions). The odor assessors were then positioned at three set locations around the primary facility and, whenever odor was detected, made a full set of readings there. Lastly, the assessors were positioned at a downwind location along the perimeter of the site, about 50 to 100 feet (15-30 m) away from the primary facilities, to make a final round of readings. Readings were taken at the site last to prevent any lingering influence of breathing in relatively odorous air near the facilities on readings taken at more remote locations.

Data Analysis:

Collected measurement data was promptly entered into a spreadsheet database. Preliminary evaluations of the data were performed to assess the extent of variation between participants and to determine whether outlier analysis would be performed.

In the main analysis of data, each round of readings made by an individual assessor for a given time and location was evaluated as a single assessment. The 12 mask DT and odor intensity readings for each individual assessment were averaged and subsequently analyzed as mean DTs and intensities. Geometric means were not used at this point since, to accurately monitor an odor plume in the field over even short periods of time, variation in an individual's readings was expected.

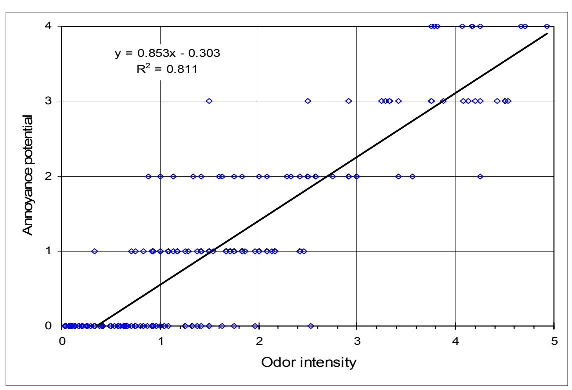
Linear regressions were performed to determine relationships between odor intensity, mask DT, and Hedonic tone (independent variables) and annoyance potential (dependent variable). The regression data were subsequently evaluated to determine reasonable thresholds for defining/predicting annoying states of odor. Thresholds were delineated as causing either any degree of annoyance (slightly annoying and greater, Annoy $\geq$ 1) or consequential annoyance (moderately annoying and greater, Annoy $\geq$ 2). Prospective thresholds were then evaluated based upon annoyance frequency and rates of false positives and negatives.

Results and Discussion

Odor was detected in 241 of the individual assessments (312 total) made by mobile odor assessors in 2005. The state of odor was considered to be at least slightly annoying in 113 individual assessments (47%) and consequentially annoying - implying that the state of odor would likely influence assessor behavior - in 58 (24%) of the assessments.

Odor Intensity:

The perceived potential for odor annoyance increased with measured odor intensity (Figure 2), and annoyance correlated reasonably well with intensity (r^2 = 0.81). The data show that an intensity of 1.5 corresponded with slight annoyance and an intensity of about 2.5 (2.7) corresponded with moderate annoyance. Recall that moderate annoyance was the least state of annoyance at which the receptor would alter their behavior or activity level, or the threshold of consequential annoyance. Considering the conservative limits of



a 90% confidence interval (receptor-friendly view), an intensity of 1 (actually about 0.75) corresponded with slight annoyance, and an intensity of 2 corresponded with moderate annoyance.

Figure 2. Relationship between perceived odor annoyance potential and measured [field] odor intensity.

A histogram can show where a sudden increase in the frequency of reported annoyance potential occurs. According to Figure 3, the thresholds for any annoyance and for consequential (moderate or greater) annoyance occur for assessed odor intensities of 1 and 2.5, respectively.

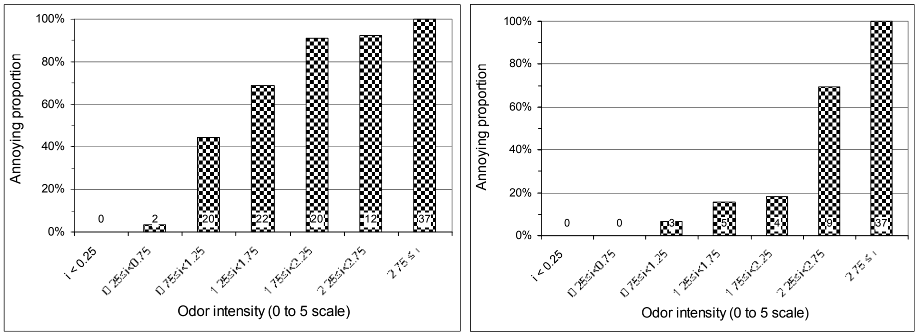


Figure 3. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor intensity. The number at the bottom of each bar indicates the number of responses indicating annoyance within the given range.

Another way to evaluate thresholds is to consider prediction error rates. Figure 4 shows the trends in prediction errors when the threshold for annoyance is set incrementally at intensities of 0.5 up to 3, for any annoyance and for consequential annoyance, respectively. A "false +" error refers to a situation where an intensity exceeded the assigned threshold, but the receptor did not rate the state of odor as being annoying, and a "false -" error refers to a situation where an intensity did not exceed the threshold value, but the receptor did rate the state of odor as being annoying.

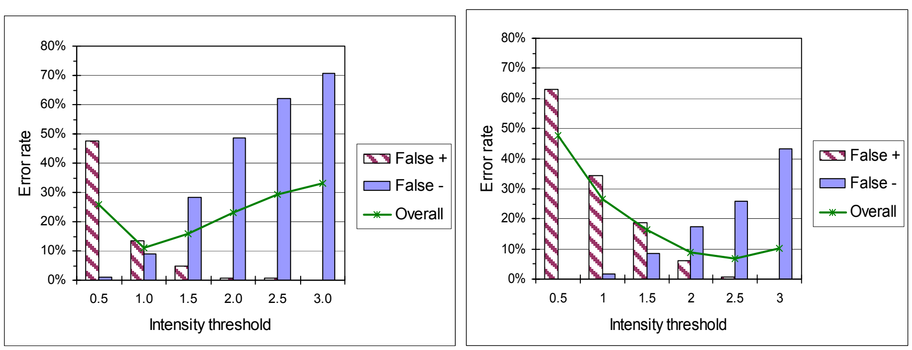


Figure 4. Error rates when using odor intensity to predict odor annoyance (left) and consequential annoyance (right), shown as functions of the threshold odor intensity.

The false-positive error rate for predicting any annoyance ranged from about 48% (61/128) at a 0.5 intensity threshold to below 1% for i ≥ 2 (Figure 4, left graph). The false-negative error rate ranged from below 1% for a 0.5 threshold to over 70% (80/113) at i = 3. The data illustrate the challenge involved in trying to catch all objectively reported annoying odor conditions, in that a high false-positive rate would need to be endured, and visa versa. The minimum number of errors overall occurred for an intensity threshold of i = 1.0. The false-positive error rate in identifying odor states that were likely to lead to changes in behavior or activity level ranged from about 63% (115/183) at a 0.5 intensity threshold to below 1% for i ≥ 2.5 (Figure 4, right graph). The false-negative error rate ranged from 0% at an intensity threshold of 0.5 to about 43% (25/58) at i = 3. The minimum number of errors overall occur for an intensity threshold of i = 2.5, but a lower threshold may be needed to avoid not catching a sizeable percentage of objectively reported, consequentially annoying odor conditions.

Odor Concentration:

The perceived potential for annoyance also increased with measured odor concentration (Figure 5), and annoyance was moderately correlated with concentration ($r^2 = 0.64$). Odor concentrations of around 4 D/T and 11 D/T, using field olfactometry, corresponded with slight and moderate annoyance, respectively.

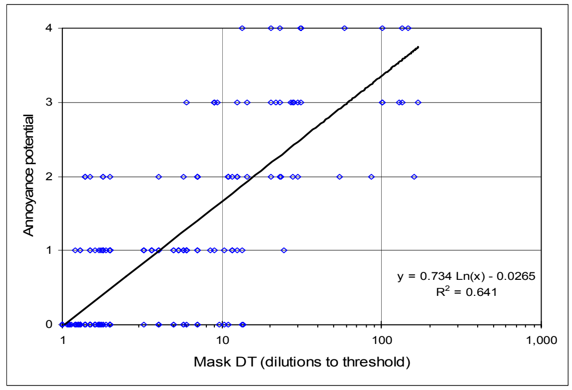


Figure 5. Relationship between perceived odor annoyance potential and measured (mask scentometer) odor concentration.

When the odor concentration measured using a mask scentometer was reported to exceed 15 D/T, over 90% of the assessor responses indicated that potential for consequential odor annoyance existed (Figure 6). Given that the definition of odor annoyance would likely be defined at a lower frequency (i.e. 67%, 50% or lower), the threshold for any degree of annoyance appears to be between 2 and 15 D/T (Figure 6, left graph), while the threshold for consequential annoyance appears to be between 7 and 31 D/T (Figure 6, right graph).

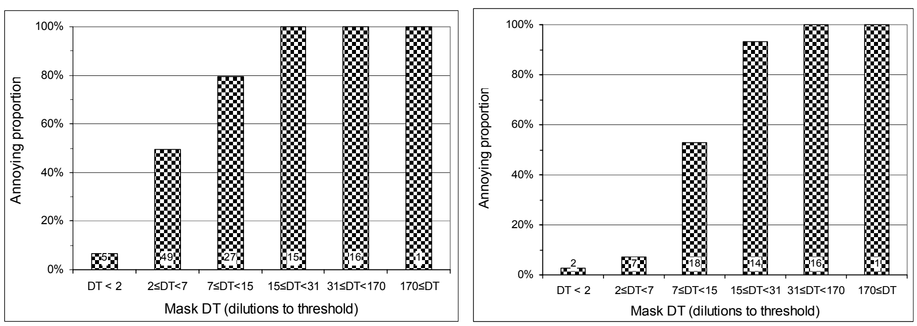


Figure 6. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor concentration. The number at the bottom of each bar indicates the number of responses indicating annoyance within the given range.

The false-positive error rate for predicting any annoyance ranged from 100% (by default) for odors that were not detectable at a 2:1 dilution ratio (128/128) to 0% for a concentration threshold of 15 D/T (Figure 7, left graph). The false-negative error rate started at 15% and was over 99% (112/113) for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 2 D/T. The false-positive error rate in identifying odor states that were likely to lead to consequential annoyance ranged from 100% for odors that were not detectable at 2:1 dilution (183/183) to below 1% for an odor concentration threshold of 15 D/T (Figure 7, right graph). The false-negative error rate started at about 9% and was over 98% (57/58) for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 7 D/T.

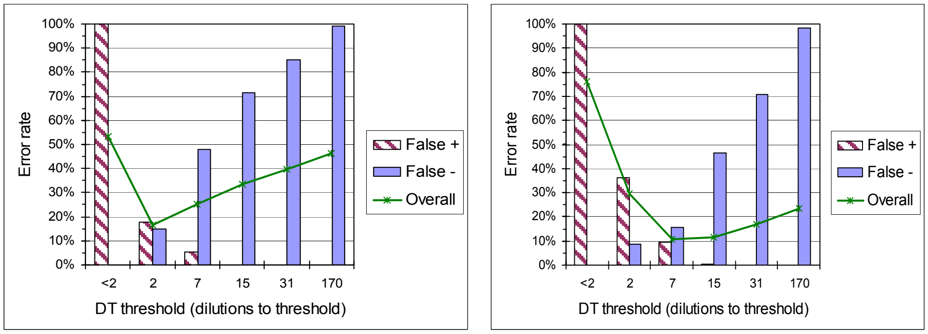


Figure 7. Error rates when using odor concentration to predict odor annoyance (left) and consequential annoyance (right), as a function of the threshold concentration (via mask scentometer).

Hedonic Tone:

Hedonic tone is presented in terms of an offensiveness rating (0 to 4), since no positive Hedonic tone ratings were provided by the assessors. A fairly strong correlation (r^2 = 0.89) existed between the perceived potential for odor annoyance and odor offensiveness (Figure 8), and a nearly 1-to-1 association between the two ratings is evident (slope = 0.97). The assessors in this study clearly associated the offensiveness of odor with the potential for the odor to be annoying. This occurred despite the fact that the two parameters were assigned differing non-numeric scales and had a different basis for receiving a rating.

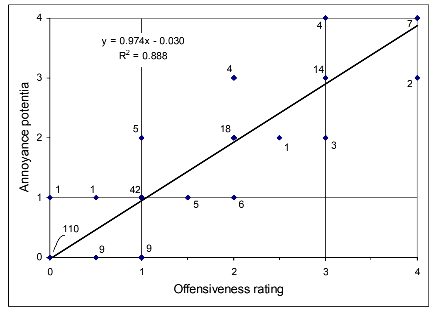


Figure 8. Perceived odor annoyance potential as influenced by odor offensiveness.

Measurement of hedonic tone is much more subjective than is measurement of odor intensity or concentration, however, and one could question the merits of comparing two ratings, which involve perceptions about odor. Both rating scales could be envisioned as being 4-level scales, which could also contributed to the nearly 1:1 association. Unfortunately, quantitative analysis and prediction using dispersion modeling cannot directly use hedonic tone ratings.

Odor Character:

The descriptive information collected by assessors was examined, but was not used in subsequent analysis, due to challenges in assigning quantitative values to descriptive terms and the limited variety of resulting responses. The terms used most often to describe the odor being assessed were “manure” / “pig manure”; “pigs” / “animals”; and “earthy”.

Summary and Conclusions

Data from the first year of a field odor-monitoring study were analyzed to compare assessor measurements of odor intensity, concentration, and hedonic tone against assessor ratings of perceived odor annoyance potential. The following conclusions were made about the strength of associations between these measures and annoyance, and about candidate thresholds for defining annoying states of odor:

1) Positive correlations with annoyance exist for the 3 assessed odor measures with the ranked order of correlations being offensiveness (r^2 = 0.89), intensity (r^2 = 0.81), and concentration (r^2 = 0.64).

2) Selection of threshold values for defining odor annoyance depends on whether the intent is to describe any degree of perceived odor annoyance or only ‘consequential annoyance’, in which the coinciding behavior or activity level of the odor receptor is likely to be affected and some memory of the odor event will probably persist after the event or exposure to the odor ends. Candidate thresholds for the three field measures at each of the two levels of annoyance are as follows:

	Any Annoyance	Consequential Annoyance
Intensity (0-5 scale)	1	2
Concentration	2 D/T	7 D/T
Hedonic tone	-1	-2

Opportunities for Further Study:

The data collected in this study provide evidence that, in field conditions, an intensity of 2 and potential for consequential odor annoyance correspond with an odor concentration of 7 to 15 dilutions to threshold. This suggests that selecting a threshold odor concentration within this range when predicting the presence of annoying odor levels may represent actual conditions more closely than using a value determined based upon relationships of concentration and intensity data (e.g. i of 2 ➔ 75 D/T) collected in an olfactometry laboratory. In regard to dispersion modeling, use of a lower odor concentration threshold may result in smaller scaling factors being needed to bring model predictions in line with field observations made in rural community settings.

Halverson (2006) developed a fuzzy logic model based upon preliminary data from this study to describe odor annoyance as function of odor intensity, concentration, and hedonic. Further inquiry into what constitutes annoyance and guidance on acceptable limits on error rates are needed.

Acknowledgements. This study was supported by a grant from the Nebraska Pork Producers Association.

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